OPTIMISATION OF A CONDENSATE RECOVERY SYSTEM

MUHAMAD FAEZ BIN LUKMAN

A project report submitted in fulfilment of the
requirements for the award of the degree of
Master of Science (*Energy Management*)

School of Chemical and Energy Engineering
Faculty of Engineering
Universiti Teknologi Malaysia

AUGUST 2019

DEDICATION

This project report is dedicated to my mother, who will keep on encouraging me to be better person and never to give up on succeeding in life.

ACKNOWLEDGEMENT

In preparing this project report, I was in contact with many people, researchers, academicians, and practitioners. They have contributed towards my understanding and thoughts. In particular, I wish to express my sincere appreciation to my main project report supervisor, Ir Dr Lim Jeng Shiun, for encouragement, guidance, critics and friendship. Without their continued support and interest, this project report would not have been the same as presented here.

I am also indebted to Universiti Teknologi Malaysia (UTM) for the facilities and the NPF scholarship that I received during my master's study.

My fellow postgraduate student should also be recognised for their support. My sincere appreciation also extends to all my colleagues and others who have provided assistance at various occasions. Their views and tips are useful indeed. Unfortunately, it is not possible to list all of them in this limited space. I am grateful to all my family member.

ABSTRACT

In the past few years the energy demand in the world kept on increasing year by year. The part that will be focused is the designing of the condensate recovery system to optimise the system is how much condensate should be recovered and at what is the usage of equipment need in the designing of the equipment with the cost. The problems that will be addressed are minimising the cost of make-up water and energy. Suitable design based on the condensate condition of the condensate presence in the system is addressed also. In pharmaceutical industries, around 35 to 70 per cent of the condensate along with significant quantity of heat is being drained to the effluent treatment plant (ETP). Two objectives is considered in this research which is to develop an optimisation model of a condensate recovery system, with the objective of maximising the economic potential and to apply model on a case study to determine potential savings of condensate recovery system. The scope started with the data collection on the condition of the condensate based on the case study then proceed with the designing of each piping, pump and system type equipment. Then he parameters to design the system such as what time of systems, pumps and piping will be calculated and used in the construction of the superstructure. Then the formulation of the optimisation of the thermal energy system is formulated. Then the data will be input into the formulation and run it into GAMS modular software. Then the results are recorded and see how much energy is conserved and how much of the system is optimised. The modelling optimisation was successful and the maximum economic potential was recorded. The pipe, pump and system type were chosen the optimal in this case study. The conclusion in this research is the optimisation of the condensate recovery system economic potential is at 128915 $. This research can contribute to the reduction of energy demand in the thermal energy system.

ABSTRAK

Dalam beberapa tahun kebelakangan, permintaan tenaga di dunia terus meningkat tahun demi tahun. Bahagian yang akan difokuskan ialah reka bentuk sistem pemulihan kondensat untuk mengoptimumkan sistem adalah berapa kondensat perlu dipulihkan dan pada penggunaan peralatan keperluan dalam merancang peralatan dengan kos. Masalah yang akan ditangani ialah meminimumkan kos air dan tenaga make up. Reka bentuk yang sesuai berdasarkan keadaan kondensat kehadiran kondensat dalam sistem juga ditangani. Dalam industri farmaseutikal, kira-kira 35 hingga 70 peratus daripada kondensat berserta dengan kuantiti haba yang ketara disalurkan ke loji rawatan efluen (ETP). Dua objektif dipertimbangkan dalam kajian ini iaitu untuk membangunkan model pengoptimuman sistem pemulihan kondensat, dengan matlamat memaksimumkan potensi ekonomi dan menerapkan model kajian kes untuk menentukan penjimatan potensi sistem pemulihan kondensat. Skop ini bermula dengan pengumpulan data mengenai keadaan kondensat berdasarkan kajian kes itu kemudian meneruskan dengan merancang masing-masing pipa, pam dan peralatan jenis sistem. Kemudian dia membuat parameter untuk merancang sistem seperti masa sistem, pam dan pipa akan dikira dan digunakan dalam pembinaan struktur superstruktur. Kemudian perumusan pengoptimalan sistem tenaga termal dirumuskan. Kemudian data akan dimasukkan ke dalam formulasi dan jalankan ke dalam perisian modular GAMS. Kemudian hasilnya direkodkan dan lihat berapa banyak tenaga yang dipelihara dan berapa banyak sistem yang dioptimumkan. Pengoptimuman pemodelan berjaya dan potensi ekonomi maksimum direkodkan. Jenis paip, pam dan jenis sistem dipilih dengan optimum dalam kajian kes ini. Kesimpulan dalam kajian ini ialah pengoptimuman sistem pemulihan kondensat yang berpotensi ekonomi pada 128915 $. Penyelidikan ini boleh menyumbang kepada pengurangan permintaan tenaga dalam sistem tenaga haba.

TABLE OF CONTENTS

	TITLE	PAGE
	DECLARATION	**iii**
	DEDICATION	**iv**
	ACKNOWLEDGEMENT	**v**
	ABSTRACT	**vi**
	LIST OF FIGURES	**xi**
	LIST OF TABLES	**xiii**
	LIST OF EQUATION	**xv**
CHAPTER 1	**INTRODUCTION**	**1**
1.1.	Introduction	1
1.2	Problem Statement	6
1.3	Objective	9
1.4	Scope of study	10
CHAPTER 2	**LITERATURE REVIEW**	**13**
2.1	Penicillin	13
2.2	Pharmaceutical process	16
2.3	Batch Process	21
2.4	Thermal Energy System	24
2.5	Condensate Recovery	26

2.6 Design of Condensate Recovery System 29

2.7 General Algebraic Modelling System (GAMS) 38

2.8 Linear Programming and Multiple IntegerLinear Programming 42

2.9 Non-Linear Programming 48

CHAPTER 3 METHODOLOGY 51

3.1 State of Art 51

3.2 Data Collection 54

3.3 Potential Savings 55

3.4 Design of The Condensate Recovery System 59

3.5 Superstructure 62

3.6 Develop the Mathematical Model 63

3.7 Expected Results 64

CHAPTER 4 RESULTS AND DISCUSSION 67

4.1 Introduction 67

4.2 Economic Analysis 67

4.3 The Piping Design 78

CHAPTER 5 CONCLUSION AND RECOMMENDATION 97

5.1 Conclusion 97

5.2 Recommendation 98

REFFERENCE 99

APPENDIX 105

LIST OF FIGURES

FIGURES NO.	TITLE	PAGE
Figure 1.1.1	The primary energy consumption by end use sector from year 2012 to 2040	2
Figure 1.1.2	Global gross output (trillion $) by industrial subsector year 2012 and 2040	3
Figure 2.1.1	The 2D structure of Penicillin V	14
Figure 2.1.2	Antibiotics sales by class in 2009 in US$ billions	16
Figure 2.2.1	Generalized block diagram of downstream processing	20
Figure 2.3.1	The batch production of Penicillin V (Harding and Harrison, 2016)	22
Figure 2.4.1	The thermal energy demand in the batch process system.	25
Figure 2.5.1	The water changing states based on heating. (Tlv.com, 2019)	27
Figure 2.6.1	Type of condensate line diagram (Beta.spiraxsarco.com, 2019)	30
Figure 2.6.2	The centrifugal pump used in a condensate recovery system(Tlv.com, 2019)	34
Figure 2.6.3	The mechanical condensate pump in a condensate recovery system (Tlv.com, 2019)	35
Figure 2.6.4	The vented system of condensate recovery (Tlv.com, 2019)	36

Figure 2.6.5	The pressurised condensate recovery system (Tlv.com, 2019)	37
Figure 2.7.1	Basic block diagram to understand the correct sequence of GAMS	40
Figure 3.1.1	The flowchart of the methodology	53
Figure 4.2.1	The total savings based on type	77
Figure 4.3.1	Condensate piping chart for discharge lines	84
Figure 4.3.2	The centrifugal pump sizing	86
Figure 4.3.3	The mechanical condensate recovery for DN50 mechanical pump	89
Figure 4.3.4	The superstructure for the condensate recovery optimisation	91
Figure 0.1	The objective function and parameters in the optimisation	105
Figure 0.2	The variables involved in the optimisation	106
Figure 0.3	The Equation involves in the optimisation	107
Figure 0.4	The equation details	108
Figure 0.5	The equation details (continued)	109
Figure 0.6	The equation details (continued)	110
Figure 0.7	The Solve summary of the optimisation	111
Figure 0.8	The lower, level, upper and marginal value of each equations.	112
Figure 0.9	The final results of the optimisation	113
Figure 0.10	The final report summary on the optimisation.	113

LIST OF TABLES

TABLE NO.	TITLE	PAGE
Table 4.2.1	The water cost	68
Table 4.2.2	The total cost	69
Table 4.2.3	The Fuel cost	70
Table 4.2.4	The Chemical Cost	71
Table 4.2.5	The Pre-treatment cost	73
Table 4.2.6	The Blowdown cost	75
Table 4.2.7	The Total cost per year	76
Table 4.3.1	Nominal surface area of steel pipes per metre length	78
Table 4.3.2	Calculated values for the drain return lines	79
Table 4.3.3	The flow of water in pipes	80
Table 4.3.4	The drain to trap final diameter sizing	80
Table 4.3.5	The common return lines for the condensate recovery system.	81
Table 4.3.6	The discharge line from trap sizing	82
Table 4.3.7	The cost of each type of pipe.	83
Table 4.3.8	The data calculated on the centrifugal pump	87
Table 4.3.9	The mechanical condensate sizing	88
Table 4.3.10	The data on pumps	93
Table 4.3.11	The data on the type of system	94

Table 4.3.12	The variables of the modelling in GAMS	95
Table 4.3.13	The total cost of the system	95
Table 4.3.14	The type of system chosen	96
Table 4.3.15	The life cycle cost for 1-year operation	96

LIST OF EQUATION

TABLE NO.	TITLE	PAGE
Equation 2.8.1	Formula of linear programming	42
Equation 2.8.2	Integer Formula 1	44
Equation 2.8.3	Integer formula 2	44
Equation 2.8.4	Binary formula	45
Equation 2.8.5	Semi continuous variable formula	46
Equation 2.9.1	Non-linear programming	48
Equation 3.3.1	The water and sewer cost calculation	56
Equation 3.3.2	The fuel cost calculation	56
Equation 3.3.3	The chemical cost calculation	56
Equation 3.3.4	The pre-treatment cost calculation	57
Equation 3.3.5	The blowdown cost calculation	58
Equation 3.4.1	The formula needed for process to trap design	59
Equation 3.4.2	The proportion of flash steam equation	60
Equation 3.4.3	The common return line equation	60
Equation 3.4.4	The pump type calculation	61
Equation 3.4.5	The mechanical condensate pump sizing	62
Equation 4.3.1	The payback period of the optimisation	96

CHAPTER 1

INTRODUCTION

1.1. Introduction

The energy demand in this world for the past few years shows an increasing trend. It depends on many factors which are the end use sector, region and the fuel used. The only factor that will be looked into for this research is the sector of the energy demand which consist of transport, industry, non-combusted and buildings. The industrial sector accounting for around half of the overall increases in demand compare to all of the other sector (Dale, 2018). The industrial sector consumes about 54% of the world's total delivered energy as you can see from figure 1 below (U.S. Energy Information Administration, 2016).

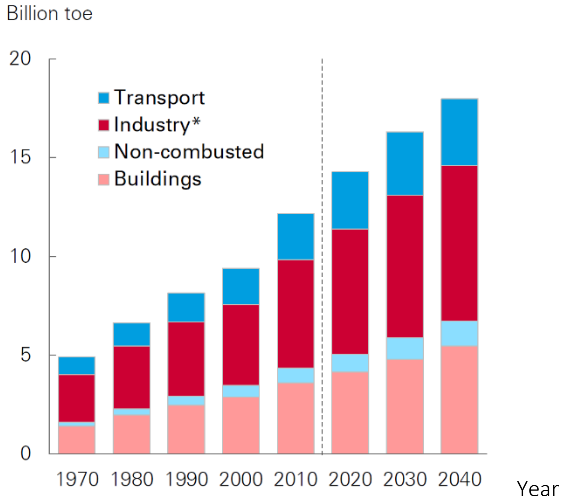

Figure 1.1.1 The primary energy consumption by end use sector from year 2012 to 2040

The industrial sector can be categorized by three distinct types which are energy – intensive manufacturing, nonenergy – intensive manufacturing and nonmanufacturing. The difference from the energy – intensive manufacturing and nonenergy – intensive is that the uses of energy in the energy – intensive manufacturing is lower compare to the nonenergy – intensive. While with the difference between nonmanufacturing industries compare to the other two groups is it does not involve any manufacturing or production. Examples of energy – intensive manufacturing industry are food, paper and refining industries. Nonenergy – intensive manufacturing are pharmaceuticals, bioprocess and electronics production. Nonmanufacturing industries are such as agriculture, mining and construction. You can see from this point that the process industries consume most of the energy and by the year 2040 it is predicted that the nonenergy – intensive manufacturing will consume 43% of the consumption of energy as shown in figure 2 (U.S. Energy Information Administration, 2016).

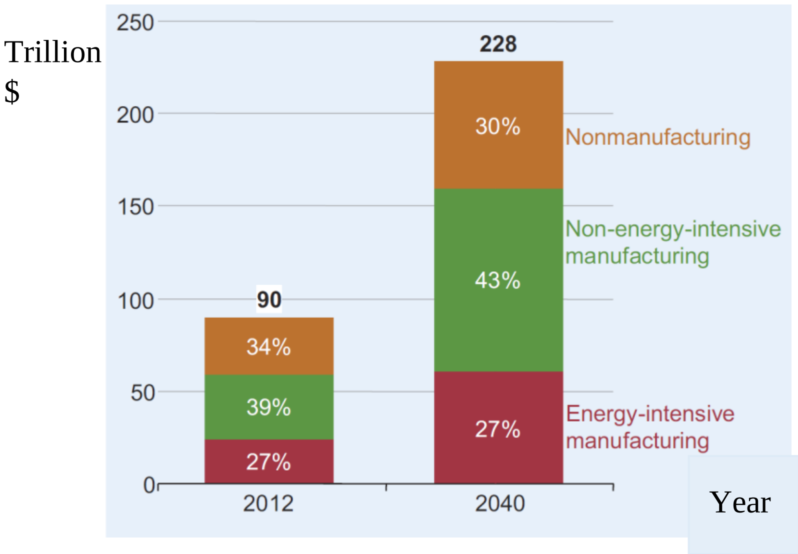

Figure 1.1.2 Global gross output (trillion $) by industrial subsector year 2012 and 2040

Next, the problems that industries have especially nonenergy – intensive manufacturing industries is that the demand of energy will keep on increasing other than reducing it or optimizing the energy demand. One example of the industries in the non-energy intensive manufacturing is the pharmaceutical industry. Over the last decade, the increase economic headwinds and rising energy costs, energy consumption is being much more critical. The pharmaceutical industry is wants to lower the cost of energy and even pushing towards more environmental stewardship and carbon reduction in light of larger global environmental trends. The energy use by pharmaceutical industries usually divided into two which are electrical or utilities energy and thermal energy. Electrical energy is the energy needed for the plant to produce their product, to run all the equipment, provide energy to the necessary devices such as lighting and air conditioning to make sure that the whole system of the plant is running smoothly. The thermal energy is a system that provided the process in upstream and both down streams with heated water or steams and chilled water to make sure the process is running at the desired temperature and state. This study will only focus on the optimisation of the thermal energy system to reduce the energy consumption of a process industry (Berrada and Loudiyi, 2015).

One type of process of process industries that is focused in this industry is batch process. Batch process is a process that based on the production of bio – based chemical and materials, fuel and pharmaceutical products. In other terms it is also knows as the production of useful products involving biological process within bioprocessing plants. This industry has been rapidly developing and have impacted various sectors of industries over the last several decades. In today’s technologies it represents an essential part of food, chemical, pharmaceutical and other similar industries where bio-based product manufacturing is carried out by using a wide range of solvents and utilities. Some pharmaceutical company even changed into using bioprocess as a way for them to produce their drugs (Anastasovski, Rašković and Guzović, 2015). The process plant of a bioprocess industry is similar to another process plant but a more complex task due to the type of process that carried out. Usually in a bioprocessing plant they consider to be a batch processing plant (BPP) than continuous processing plants (CPP). In a BPP the operation of certain equipment has to wait for the previous equipment to finish in order for the next operation to occur. While in CPP all of the operations occur simultaneously and the production is processed without interruption. In this research, the optimisation will be focused only one part of the whole system so it is still possible to run it in a continuous way to make sure that the optimisation of the thermal energy management is done properly (Lee, Seid and Majozi, 2015).

Optimizing the thermal energy system can be done by analysing what is needed in the current system to make sure that cost can be save in running the thermal energy system. In the system it is observed that the condensate is not recovered and merely dumped into the drain system. This is known as a waste of potential energy recovery of the condensate value. Condensate recovery can reduce not just the make-up water cost but even sewer cost, fuel cost, chemical cost, pre-treatment cost and blowdown cost. Eliminating these costs can lead to a lot of energy saving opportunities and environmental benefits. A proper design of the condensate recovery needed to be installed in the system to make sure the condensate recovery that is in process is the best quality possible for the case study. The condensate recovery of a system is not the same as any other type of condensate recovery because it correlates with the conditions and situation of the condensate that is being recovered. These conditions and situations are temperature, pressure difference and type of process. After analysing the condensate properly, the size and length of piping for each part of the condensate, the type of pump and type of system need to be determined. Then the design of the condensate recovery can be completed.

1.2 Problem Statement

In conducting this research, optimising the thermal energy system of the process needs to make sure that the condensate recovery in the system can be maximised. This means that if the condensate recovery supplied after used is 100 L then the value that recovered must be near. Some considerations must be considered also which is if the condensate recovery is about 75 – 80% then the value is still reasonable for the system. Usually the reduced value of the condensate is due to the conditions of the condensate recovered which can cause fouling to the boiler. This process is called the boiler blowdown. The reason we must maximised condensate recovery is that when steam condenses, the condensate temperature is the same as the steam itself because only the latent heat has been transferred to the system, the full amount of the sensible heat remains in the condensate. Another term for this condition of the condensate is called saturated water. The sensible heat can be used back is the purpose of the condensate recovery (Lee, Seid and Majozi, 2015). The energy that is usually contain in the condensate is about 25% of the energy in the original steam. This can save a lot of cost in operating the boiler in reducing the make-up water for the boiler, reduce fuel for heating the boiler and increases the boiler lifespan.

The design of the condensate recovery can also be a problem, the reason is because the part of the design consists of many parts which is the piping, pumps and system. Then the piping sizing and length of the condensate lines need to be determined in the designing of the condensate recovery system. The four basic types of condensate lines that needed to be consider is the drain lines to trap, discharge lines from traps, common return lines and pumped return lines. The parameters that needed to be considered during sizing the condensate lines is the pressure, quantity and condition. The pump for the condensate recovery needed to be chosen based on the situation of the condensate returns. The condensate recovery can also run without any pumps needed if the design can transfer the condensate without any restriction either by using gravity or design of the piping. One pump that can be considered is that the electrical centrifugal pumps, this pump is widely used in the condensate recovery system and usually the temperature of the condensate is medium or low temperature. The condition of the pressure differences can be positive or negative. Another type of pump that can be chosen is mechanical condensate pumps which used in high temperature condensate recovery. The pressure difference of this pump is that it must be always positive. The systems of the condensate recovery need to be either a vented systems or pressurized systems. Condensate recovery systems can be classified as either vented-to-atmosphere or pressurized depending on whether condensate is recovered in an open-to-atmosphere tank (vented) or sent to a pressurized vessel either directly to the boiler (pressurized) (Beta.spiraxsarco.com, 2019).

In pharmaceutical industries, typical condensate recovery ranges between 30 to 55 percent. Average direct steam consumption, this means that knowingly or unknowingly, around 35 to 70 per cent of the condensate, along with significant quantity of heat is being drained to increase the load of the effluent treatment plant (ETP). Effluent Treatment Plant or ETP is one type of waste water treatment method which is particularly designed to purify industrial waste water for its reuse and its aim is to release safe water to environment from the harmful effect caused by the effluent. The main reasons is remotely located units in the plant, less quantity of condensate making it practically non-feasible to recover, scarcity of the water thereby imposing the use of condensate locally and lack of knowledge about the value of condensate. Out of all the above, "Lack of Knowledge" about the condensate ranks the first (A Korde, 2019). Even at most of the industries, it has been observed that the condensate is stored in the tank outside the unit and pumped electrically to cater the make-up water demand of the nearby cooling towers. This not only wastes the pure condensate with its associated heat energy but also result in increasing the load on the cooling tower itself.

1.3 Objective

a) To develop an optimisation model of a condensate recovery system, with the objective of maximising the economic potential.
b) To apply model on a case study to determine potential savings of condensate recovery system.

1.4 Scope of Study

a) Literature review is done on the product of the case study which is penicillin to understand more on the process in pharmaceutical industry.

b) Batch and the thermal energy system need to be understood and explain to make sure the understanding is complete on the operation of the system

c) Then understanding the modular GAMS is needed to identify the solver and hat type of solver needed to be use in the system either linear, mixed integer linear programming or non linear.

d) A thermal energy system of a plant is chosen as the case study and do a data analysis and collection of the system and see whether and optimisation and designing of condensate recovery system is done or not.

e) Analysed the thermal energy system in the process and take note on all of the process that is involved in the thermal energy system. The data of each output of condensate need to be analysed based on the conditions, temperature and pressure.

f) Calculate the economic potential if condensate recovery is done for all of the process annually. This will be considered based on all of the cost that is needed if the condensate is not recovered back into the system.

g) The economic potential is based on the water, sewer, fuel, chemical treatment, pre-treatment and blowdown cost of the thermal energy system of the case study.

h) Based on the conditions of each output of the condensate, the size and length of the piping needed for the design of the condensate recovery system must be calculated and recorded. Choose the appropriate piping needed based on the existing model of pipes.

i) Decide whether installing a pump in the system is needed for the condensate recovery design. If the installation of pumps is needed, decide what type of pumps that should be considered based on the condition of the condensate in the return lines.

j) The type of system of the condensate recovery design need to be chosen based on the conditions of the plant process and condensate. The decisions are usually based on the cost of the system.

k) Understand all of the components such as all of the variables, parameters and constraints of the design of the condensate recovery system based on the previous analysis done.

l) Collect all the data needed for the formation of the superstructure. Which is all type of piping involves and their cost, the cost of the pump and operating cost, the type of system installation and operation cost.

m) Classify all of the information given by its particular characteristics and organized through the identification of similar patterns for each component of the problem.

n) Then form the superstructure including all the parameters, variables and constraints based on the supply and demand of the energy of the thermal energy system.

o) Then proposed a possible solution of the problem and see which parameters is chosen for the design of the condensate recovery system based on the case study.

p) Then proceed with sensitivity analysis. Improve the variables based on the analysis and correct all the possible problems that occur in the formulation. Make sure the formulation fulfils all the problem requirements and be compare the results with the expected results to see the outcome. Discuss and conclude the research.

REFFERENCE

Anastasovski, A., Rašković, P. and Guzović, Z. (2015). Design and analysis of heat recovery system in bioprocess plant. *Energy Conversion and Management*, 104, pp.32-43.

A Korde, N. (2019). Chemical Engineering World. [online] Cewindia.com. Available at: http://www.cewindia.com/narayan_korde_features.html [Accessed 4 Aug. 2019].

Asdal, R. (1997). Pump system design and application. Pump Industry Analyst, 1997(19), p.10.

Berrada, A. and Loudiyi, K. (2015). Optimal Modeling of Energy Storage System. International Journal of Modeling and Optimization, 5(1), pp.71-77.

Beta.spiraxsarco.com. (2019). Introduction to Condensate Recovery. [online] Available at: https://beta.spiraxsarco.com/learn-about-steam/condensate-recovery/introduction-to-condensate-recovery#article-top [Accessed 4 Aug. 2019].

Chicago, U. (2018). Penicillin V | Side Effects, Dosage, Uses, and More. [online] Healthline. Available at: https://www.healthline.com/health/penicillin-v-oral-tablet#alternatives [Accessed 1 Dec. 2018].

Dale, S. (2018). Energy demand by sector. [online] bp.com. Available at:https://www.bp.com/en/global/corporate/enegry-economics/energy-outlook/demand-by-sector.html [Accessed 9 Nov. 2018].

Drugbank.ca. (2018). Phenoxymethylpenicillin - DrugBank. [online] Available at: https://www.drugbank.ca/drugs/DB00417 [Accessed 1 Dec. 2018].

Ersahin, M. (2018). Modeling the dynamic performance of full-scale anaerobic primary sludge digester using Anaerobic Digestion Model No. 1 (ADM1). Bioprocess and Biosystems Engineerin

Gari, H. and Fathalah, K. (1988). Modelling and simulation of a passive condensate heat pipe pumping system for solar energy applications. Heat Recovery Systems and CHP, 8(6), pp.559-569.

Gasmalaysia.com. (2019). Tariff & Rates. [online] Available at: https://www.gasmalaysia.com/index.php/our-services/at-your-service/bills-payments/tariff-rates [Accessed 7 Aug. 2019].

Hamad, B. (2010). The antibiotics market. Nature Reviews Drug Discovery, 9(9), pp.675-676.g, 41(10), pp.1539-1545.ology, 90(3), pp.349-355.

Improving Steam System Performance. (2012). Washington, D.C.: United States. Dept. of Energy. Office of Energy Efficiency and Renewable Energy.

Joseph, A., Kabbara, M., Groulx, D., Allred, P. and White, M. (2015). Characterization and real-time testing of phase-change materials for solar thermal energy storage. International Journal of Energy Research, 40(1), pp.61-70.

Kayfeci, M. (2014). Determination of energy saving and optimum insulation thicknesses of the heating piping systems for different insulation materials. Energy and Buildings, 69, pp.278-284.

Kiss, A., Grievink, J. and Rito-Palomares, M. (2014). A systems engineering perspective on process integration in industrial biotechnology. Journal of Chemical Technology & Biotech

Kiss, A., Grievink, J. and Rito-Palomares, M. (2014). A systems engineering perspective on process integration in industrial biotechnology. Journal of Chemical Technology & Biotechnology, 90(3), pp.349-355.

Lee, J., Seid, E. and Majozi, T. (2015). Heat integration of intermittently available continuous streams in multipurpose batch plants. *Computers & Chemical Engineering*, 74, pp.100-114.

Lee, J., Seid, E. and Majozi, T. (2015). Heat integration of intermittently available continuous streams in multipurpose batch plants. Computers & Chemical Engineering, 74, pp.100-114.

Markov, S. A. (2015). Bioprocess engineering. Austin Peay State Univeristy: ResearchGate, pp.240-245.

McDonald, J. (2019). Condensate Value. [online] Veoliawatertech.com. Available at: http://www.veoliawatertech.com/crownsolutions/ressources/documents/2/21886,Water-pp104-111.pdf [Accessed 7 Aug. 2019].

Meštrović, T. (2018). Penicillin Production. [online] News-Medical.net. Available at: https://www.news-medical.net/health/Penicillin-Production.aspx [Accessed 2 Dec. 2018].

Montoya Giraldo, O. (2017). Solving a Classical Optimization ProblemUsing GAMS Optimizer Package:Economic Dispatch ProblemImplementation. Ingeniería y Ciencia, 13(26), pp.39-63

Murakami, M. and Okubo, T. (2013). High-Efficiency and Power-Saving Closed Condensate Recovery System. JAPAN TAPPI JOURNAL, 67(2), pp.142-148.

N, I. and BC, O. (2016). Parametric Study of Enhanced Condensate Recovery of Gas Condensate Reservoirs using Design of Experiment. Journal of Petroleum & Environmental Biotechnology, 07(01).

Qi, Z., Tian, Y. and Shi, Y. (2012). Regularized Multiple Criteria Linear Programming via Linear Programming. Procedia Computer Science, 9, pp.1234-1239. 10(2), p.191.

Ranhillsaj.com.my. (2019). Water Tariff – Ranhill SAJ Sdn Bhd. [online] Available at: https://ranhillsaj.com.my/water-tariffs/ [Accessed 7 Aug. 2019].

Sarbu, I. and Sebarchievici, C. (2018). A Comprehensive Review of Thermal Energy Storage. Sustainability,

Schreiber, H., Graf, S., Lanzerath, F. and Bardow, A. (2015). Adsorption thermal energy storage for cogeneration in industrial batch processes: Experiment, dynamic modeling and system analysis. Applied Thermal Engineering, 89, pp.485-49

Seminars on storage tanks design courses on pressure vessels and piping. (1989). International Journal of Pressure Vessels and Piping, 38(3), pp.245-246.

Stamp, J. and Majozi, T. (2017). Long-term heat integration in multipurpose batch plants using heat storage. Journal of Cleaner Production, 142, pp.1492-1509.

Tartibu, L., Sun, B. and Kaunda, M. (2015). Multi-objective optimization of the stack of a thermoacoustic engine using GAMS. Applied Soft Computing, 28, pp.30-43.

Tlv.com. (2019). Introduction to Condensate Recovery | TLV - A Steam Specialist Company (International). [online] Available at: https://www.tlv.com/global/TI/steam-theory/introduction-to-condensate-recovery.html [Accessed 27 May 2019].

U.S. Energy Information Administration (2016). Industrial sector energy consumption. [online] Eia.gov. Available at: https://www.eia.gov/outlooks/ieo/pdf/industrial.pdf [Accessed 9 Nov. 2018].

Van Boeckel, T., Gandra, S., Ashok, A., Caudron, Q., Grenfell, B., Levin, S. and Laxminarayan, R. (2014). Global antibiotic consumption 2000 to 2010: an analysis of national pharmaceutical sales data. The Lancet Infectious Diseases, 14(8), pp.742-750.

Vandani, A., Bidi, M. and Ahmadi, F. (2015). Exergy analysis and evolutionary optimization of boiler blowdown heat recovery in steam power plants. Energy Conversion and Management, 106, pp.